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Collaborative Scheduling Methods: The Most Collaborative and Software to Support

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COLLABORATIVE SCHEDULING METHODS: THE MOST COLLABORATIVE AND SOFTWARE TO SUPPORT

Calvin J. Warren[1]

ABSTRACT

The purpose of this paper is to examine CII RT 362's proposed definition of collaborative scheduling, "A comprehensive process that aligns and engages stakeholders throughout the lifecycle of the project in order to coordinate activities and resources on a project and achieve its goal." This will be achieved through a literature review of its key aspects of alignment, engagement, lifecycle, coordination, and goals to see if the definition is valid. Additionally, it will then be used to evaluate the scheduling methods of Critical Path Method, Line of Balance Method, Scrum, and Last Planner System for which is the most collaborative. Finally, a review of available software support for each method is provided to inform readers of digital support available in the hopes that it will further the collaborative process. According to the analysis performed, the methods, from most to least collaborative are the Last Planner System, Scrum, Line of Balance, and the Critical Path Method. The paper advances the field by scrutinizing a proposed definition. evaluating existing methods within that term and then linking software support to those systems.

KEYWORDS

Collaboration, Schedule, Critical Path Method, Line of Balance, Scrum, Last Planner System

1.0 INTRODUCTION

CII RT 362 has created a working definition of collaborative scheduling that is as follows "A comprehensive process that aligns and engages stakeholders throughout the lifecycle of the project in order to coordinate activities and resources on a project and achieve its goal." The reason for the interest in collaboration is that significant works have found tremendous schedule and project productivity improvements based on collaboration. For example, "early collaboration" is credited with avoiding significant project costs in the Logan Airport Terminal C to E transport project Boston, MA. (Couto & Erickson, 2017), that collaborative firms operate at higher levels of performance (Dikmen, et. al., 2009), that collaboration is an indicator of profitability in a construction project (Tamer et. al., 2012)

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and even that there can be as high as a 30:1 return on federal money in Public Private Partnerships that start with high levels of collaboration (Halsted, et. al., 2016). However, as far as the author has found, the literature has offered no detailed definition of what "collaborative scheduling" should entail.

The purpose of this paper is to provide closer scrutiny to the definition proposed by CII RT 362 and see if it can be supported via current literature in the field and whether or not it can be used to evaluate existing scheduling methods for how collaborative they are or are not. This will be accomplished through a literature review to first validate the key aspects of the definition and thus itself as a whole. Following that a targeted literature review for each method and how it relates to the key aspects of the definition will be performed and result in a qualitative evaluation that will allow the methods to be compared on their collaboration against one another. Finally, the paper will examine if, and what, software is available to support each scheduling method.

For this paper the key aspects of the definition proposed will be alignment, engagement, lifecycle, coordination, and goals as key words from the CII RT 362 team's definition of collaborative scheduling. The methods that will be examined in light of the proposed definition are the Critical Path Method (CPM), the Line of Balance (LoB) method, Scrum or Agile scheduling, and the Last Planner System (LPS).

2.0 METHOD

Multiple targeted literature searches were undertaken in order to conduct a comprehensive review of existing literature to develop a definition for the key terms used in the analysis, namely, align, engage, lifecycle, coordinate, and goals within the context of CII RT362's definition of collaborative scheduling. Another was conducted to see how those key words apply to the existing scheduling methods of CPM, LoB, Scrum, and LPS. Finally, a basic review of commercially available marketing material for Primavera 6, Microsoft Project, Trello, Mondays, BIM 360, V Planner, and Touch Plan were obtained to see how well they did or did not support the planning methods listed above. The full method process can be see in Table 1 below.

Table 1: Process table for paper research methodology.

Step	Action	Outcome
0		CII RT 362 definition of collaborative scheduling
1	Choose key words from CII RT 362 definition	Align, Engage, Lifecycle, Coordination & Goals chosen
2	Choose Scheduling methods to examine	CPM, LoB, Scrum and LPS
3	Conduct literature reviews via targeted Boolean searches	List of text evidence and sources
4	Choose software to examine	P6, MS Project, Trello, Mondays, V Planner, and Touch Plan
5	Examine marketing materials for software	Identify software capabilities
6	Synthesize literature review and software capabilities and tabulate results	Final Paper

2.1 COLLABORATION LITERATURE REVIEW

Based on the CII RT362 previous efforts the working definition of collaborative scheduling for this project is, "a comprehensive process that aligns and engages stakeholders throughout the lifecycle of the project in order to coordinate activities and resources on a project and achieve its goal." A literature review was conducted to try and compare current research on scheduling as well as to develop a comparative matrix of several popular methods for scheduling to identify if any of them can be defined as the most collaborative. Finally, a review of available software and tools was conducted to categorize which might best fit with each style.

For the general review of scheduling literature, the method for finding sources used targeted Boolean searches. Utilizing a connection through the San Diego State University Library the following data bases were chosen to review: Access Engineering, ASCE Library, and Compendex (Engineering Village). The BOOLEAN terms used in each database are as follows:

"Construct" OR "Project" AND "Manage*" AND "Schedule" AND "Colla*"*

The searches were further limited to exact matches within the last ten years for each data base and within the field of project management. The search produced 16 results for Access Engineering, 356 results for the ASCE Library, and 334 records within Compendex (Engineering Village). From these results further refinement was applied to limit total results for Title and Abstract review. Limiting according to subjects regarding project management, and where construction engineering, civil engineering, or operations were the primary focus, to published journals and conference proceedings, and utilizing the English language produced the following narrowed results for Title and Abstract Review: 13 results for Access Engineering, 151 for ASCE Library, and 96 for Compendex

(Engineering Village). After abstract review, a total of 26 sources were chosen for detailed review and ultimately 20 sources for inclusion within the work. Table 2 summarizes the above.

Table 2: Results for collaborative targeted Boolean search by database.

Search	Access Engineering	ASCE Library	Compendex
Initial Results	16	355	334
Source Inclusion	0	17	3

2.2 Scheduling Method Literature Review

For work regarding the different scheduling methods and how they compare to the definition of collaborative scheduling another targeted Boolean search was performed within the same three data bases as above for materials within the last ten years, and in the English language. The search terms were as follows:

"Critical Path Method" AND ("align" OR "engage*" OR "Coord*" OR "Life Cycle")*
"Last Planner System" AND ("align" OR "engage*" OR "Coord*" OR "Life Cycle")*
"Scrum" AND ("align" OR "engage*" OR "Coord*" OR "Life Cycle")*
"Line of Balance" AND ("align" OR "engage*" OR "Coord*" OR "Life Cycle")*

The ASCE Library results for Last Planner was further refined to limit them to technical papers within the Journal of Construction Engineering and Management to refine the results to 209 for abstract review. The Compendex Results for scrum were further refined for journal articles dealing with project management and this reduced the total results to 10 for abstract review. Finally, although the Compendex returned many applicable articles only those with the full text were chosen for inclusion. The results are summarized in Table 3. Abstracts and titles were reviewed for relevance to the research question, and extent that the method was of primary focus to the work. Table 4 shows the final distribution of sources chosen for inclusion within the study.

Table 3: Results for scheduling methods targeted Boolean search by method and database

Method	Access Engineering	ASCE Library	Compendex
Critical Path Method	0	110	20
Last Planner	0	44	63
Scrum	0	7	10
Line of Balance	0	9	2

Table 4: Final number of sources included into study by database and schedule method.

Method	Access Engineering	ASCE Library	Compendex
Critical Path Method	0	3	3
Last Planner	0	2	4
Scrum	0	1	2
Line of Balance	0	2	1

3.0 LITERATURE REVIEW

The literature review will be in three parts. The first part is the structured review of the key words chosen from the collaborative scheduling definition taking time to detail each key word with text-based evidence. The second part studies the literature related to the individual scheduling methods in light of the definition of collaborative scheduling. The last part investigates the software and their features for how they might support any of the scheduling methods looked at in the first part.

3.1 CII RT 362 Definition of Collaboration

This section will move through each key word: align, engage, lifecycle, coordinate, and goals and review the literature from the first targeted Boolean search and how they relate to the CII definition. Later the results from the search and the discussion herein were used to categorize the scheduling methods' collaborative-ness in relation to each other.

3.1.1 Collaboration Definition – Align

Alignment in context of collaborative scheduling is to ensure that all stakeholders within the project share in, support, and pursue project goals. The idea of a common focus creating a successful outcome is prevalent across the literature and many authors have shown that early adoption and agreement with project goals produced high levels of success for a project (Franz et. al., 2017, Thiessen et. al., 2016; Senesco et.al., 2013). Thiessen et. al. (2016) also described this idea of putting the desired end states as the paramount drivers of project action as "shifting the paradigm."

Specific examples are readily visible as New York City tried to add resiliency across its water utility and consequently aligned all projects to meet this end state (Cohn & Brock, 2017). By clearly stating desirable end states the city could manage projects in a portfolio to take a massive sprawling system of water delivery, storm water sewers and wastewater management and increase its resiliency in the face of increasingly frequent and increasingly stronger storms. Similarly, the town of Fort Worth made desired end states the primary decision context behind renovating their Tower 55 and emphasizing alignment within the project team to the project's goals the project was very successful (Halsted et al., 2016).

Tied to alignment and coordination are also the concept of complexity. Safapour et al. (2018), worked to show how additional project complexity made projects have greater numbers of change orders. As stakeholders rose there were problems observed with decision making leading to increased numbers of change orders, but had the stakeholders developed a more intentional communication plan to produce better collaboration and shared alignment with the desired end states, the negative end state could have been avoided. Another aspect associated with increased complexity is increased risk. Sharing this risk across the stakeholders by pooling risks as a project rather than per several individual contracts allowed individual entities to shift from managing their individual exposure to meeting project goals (Nelson & Burnworth, 2016).

Additional support for the idea of alignment as a key aspect of collaboration around shared end states came from the idea of contingency theory where by aligning contextual and environmental factors construction firms are able to reach sustained levels of high performance (Deng & Smith, 2014). The alignment of those factors amounts to practical steps taken so that the organization of the firm and the environment, or culture around the project, is tailored to meet the needs of the project.

The common theme addressed in all of the above examples could be summarized simply that if a group of people want to make progress towards a destination they must be in agreement on where they are going. Alignment in collaborative scheduling is when all stakeholders agree on the desired project end states or final outcomes to be achieved. A scheduling method that fully implements alignment will make it a point to gain consensus on project goals early in the project and make sure that alignment is maintained throughout the lifecycle of a project.

3.1.2 Collaboration Definition – Engage

Engagement, in the context of collaborative scheduling, is to actively pursue the involvement of all stakeholders. That is to say an engaging scheduling method is one that through its very nature seeks the input of stakeholders. Examples of engagement of stakeholders producing success in projects in the literature can be seen in the Logan Airport Terminal C to E connector where different team members were actively encouraged to participate in the planning process to allow for the complex project to be completed with minimal impact on airport operations (Couto & Erickson, 2017). Miami-Dade Water & Sewer Department (MDWSD) sought key stakeholders along a forty-eight-inch water main project to speed permitting (Maristany, et. al., 2017). In this case MDWSD was engaging these stakeholders to achieve accelerated permitting by walking them through the work to be performed.

Franz et al. (2017), who studied the impact of team integration on project delivery, contended that colocation increased group cohesion and was a major benefit for project delivery. It could be argued colocation increased cohesion because members were more able to engage with one another. Another study that looked at team dynamics as a predictor of Construction project success showed that projects that had a higher team satisfaction performance index (SPI) were far more likely to succeed. The index was developed from the average of responses to team members' input regarding the influence they have on their job, pay and conditions, sense of achievement associated with their work, and the respect they received from supervisors (Leon et al., 2018). However, just seeking out this information during the project raised teams' morale and increased their SPI when compared to teams asked only at the end. The act of asking, was an act of engagement and began collaborative efforts to improve the project.

In developing software, complex algorithms can be constructed to help solve many problems but when the algorithm comes to a bifurcation with two correct possibilities, essentially a difference of opinion, the development team members need to be consulted in a collaborative fashion to determine the best course of action (Koegel, et. al., 2009). This asking in development is another example supporting the definition of engagement in collaboration.

To engage stakeholders is to actively seek out they're expertise to ensure that commitments represent honest best efforts without creating false expectations. It is the act of showing mutual respect between project team members and a necessary exchange of candid information from owner to tradesman and tradesman to owner. A scheduling method that is considered to fully implement engagement is one that regularly seeks feedback from all stakeholders as it develops activity relationships and durations.

3.1.3 Collaboration Definition – Lifecycle

Lifecycle is largely self-explanatory and includes all stages of the project from programming though design, construction, substantial completion and project closeout. However, in this context it should be seen as a commentary also in how early teams are brought together in the project. Delivery methods that integrated project teams earlier in the lifecycle were found to have high measures of success (Franz et. al., 2017).

The collaboration of teams earlier in the lifecycle of a project indicating success were also evidenced in success stories mentioned earlier regarding the Tower 55 project in Fort Worth by coordinating with train operations from each railroad from planning through construction (Halsted, et. al., 2016). Additionally, early and frequent collaboration between multiple partners allowed the Berkeley Art Museum and Pacific Film Archive expansion to employ unique shoring solutions at each bulkhead ultimately culminating in a successful project with sizable cost and schedule efficiencies (Nelson & Burnworth, 2016).

Lifecycle is truly the cradle to grave process of a project from inception to closeout. And in the context of collaborative a method that is more collaborative is one that brings team together earlier as opposed to later, believing that all stakeholders have value to add to a project through applying their expertise in project's schedule development.

3.1.4 Collaboration Definition – Coordination

A definition for coordination was found in the literature that defined coordination as managing the "collective efforts of the client, designer, contractor, and other project participants," and conducted, "primarily in terms of conflicts, communications, and goal alignment" (Wen, et. al., 2017). Examples of effective coordination are seen in the Logan Airport Terminal Connector (Cuoto & Erickson, 2017), the Tower 55 public partnership (Halsted, et. al., 2016), and the MDSWD watermain installation (Maristany, et. al., 2017).

A new outlook for coordination was also exhibited in the Long Beach Middle Harbor Automated Container Terminal where several interdisciplinary and typically unrelated technical teams needed to come together to complete "North America's most advanced and environmentally responsible 'green' automated terminal" (Thiessen, et. al., 2016). The owner, contractor, engineers, and operators all needed to conduct activities in tandem to complete the project and controlled these activities through frequent meetings for real time communication. Additionally, their organization involved many overlapping teams working with a core team focused on the coordination of the actions (Thiessen, et. al., 2016). As mentioned in the alignment section Safapour et. al. (2018) demonstrated that as project complexity increased change orders grew. One of the reasons for this was more stakeholders were added as project complexity grew and this required greater and greater levels of coordination in organizations that, unlike the Long Beach Middle Harbor Automated Container Terminal, were unable to facilitate such complex interactions.

Coordination can also be seen across phases of a project when it shifts from design into construction. Klemt-Alber et. al. (2017), argue that after initial design project architects could work with precast concrete production facilities to improve construction efficiency. By developing a sophisticated catalogue of precast elements in coordination with precast facilities architects would be able to maintain freedom of design while still meeting pressing client schedule and production goals.

Coordination within collaborative scheduling is the process of ensuring activities owned by various entities who are enabled to run as planned with minimal interference from predecessors, simultaneous, and following activities. A scheduling method that fully incorporates coordination is one that shows different stakeholders working together to ensure that activities are as enabled as possible.

3.1.5 Collaboration Definition – Goals

Similar to lifecycle the definition of goals is fairly consistent to a standard definition of desired end states in a project. Project team members all approach any given project with a host of goals that may be well outside the traditional iron triangle of schedule, cost, and quality (Koops, et. al, 2017). Furthermore, as complexity increases identifying these goals also increases (Choi, et. al., 2018). Bringing these goals into the open early to drive project planning is essential to project success for all stakeholders. When goals were laid out early and used as a planning tool to align stakeholders great project success was found. The examples listed in the previous subsections all began with developing a strong sense of the project's desired end state, goals, and then using those to determine project scope and drive execution (Couto & Ericson, 2017, Halsted et. al., 2016, Thiessen, et. al., 2016).

In the context of collaborative scheduling it is important to realize that the goals must be concrete, actionable, shared across all stakeholders, specific to the project, and developed very early in the planning process in order to be of the most value. A scheduling method that has a fully implemented goals criteria is one that explicitly states goals that fit the above and fixates them as guide to direct project activities.

3.1.6 Discussion

The definitions proposed and supported above reveal some interesting connections between the key words of CII RT 362's working definition. Goals and alignment are permanently linked in that if a group fails to develop strong goals then it is impossible for alignment to occur. Alignment is ultimately the act of bringing all stakeholders to consensus regarding the project goals. Similarly, coordination and engagement are linked. Engaging stakeholders is the means to which ensure proper coordination is achieved to enable execution of the myriad and complex activities within a project. To properly coordinate the principal participants needed to find ways to both build formal actions and informal relationships that engage each other throughout the life of the project. The lifecycle aspect is a reminder that this cycle of alignment to goals and engagement for better coordination must be continuously performed throughout the course of a project from programming through closeout.

With these relationships in mind the process becomes regular and cyclic. As a problem, or an unforeseen condition, appears the project team must work together to develop an appropriate response. The goals of the project are consulted to ensure the response is in alignment with the goals. Then the members engage one another to coordinate this response and determine secondary and tertiary effects that will then need further alignment, and coordination. This process would then continue throughout the lifecycle of the project.

3.2 Scheduling Methods Evaluated by Collaborative Definition

This section will cover each scheduling method and how they are or are not collaborative based on textual evidence provided from the literature. The method for obtaining the works is described under method in section 2.2. A summarization of what sources were found as they relate to each scheduling method is included in Table 5.

Table 5: Summation of works supporting each scheduling method.

Scheduling Method	Source	Information
Critical Path Method	Christodoulou, 2018	Inaccurate
	El-Sabek & McCabe, 2018	Strong at complex high-level plans; Poor communication tool
	Hammad et. al., 2018	Inadequate attention to non-critical path activities; Inaccurate
	Zareei, 2017	Allows float calculations; Top down implementation
	Said & Lucko, 2016	Allows float calculations; Addresses milestones
	Koskela et. al., 2014	Contract management more than production planning; Top down implementation
	Goedert & Sekpe, 2013	Lacks ability to convey "intangible aspects" of the project
	Su et. al., 2013	Robust software support; Top Down Implementation; lacks capacity for spatial constraints
Line of Balance Method	Deschamps et. al., 2015	Visual Nature encourages engagement; emphasizes work flows perhaps to the detriment of other aspects of production; Focus on repetitive projects
	Koskela et. al., 2014	Based on the continuity principle
	Zhang et. al., 2014	Visual nature encourages engagement; Can incorporate learning curves; Focus on repetitive projects
	Sacks et. al., 2009	Focus on repetitive projects
Scrum Method	Dingsoyr et. al., 2018	Focused on small team; very engaging; scalable to larger projects; maintaining clear goals over a large project is difficult
	Lee & Young, 2013	Customer focused and team engaged; Limited focus on a project's lifecycle
	Fruchter & Ivanov, 2011	Emphasis on engagement throughout lifecycle; Aligning small teams to large project goals is challenging

Last Planner Method	Ebbs et. al., 2018	States as collaborative; Make ready plans build coordination; Improved project performance
	El-Sabek & McCabe, 2018	Seeks firm commitments from those who own the work; Make ready plans build coordination; PPC aligns to goals;
	Hunt & Gonzalez, 2018	Seeks firm commitments from those who own the work; Focus on process improvement; Improved project performance;
	Torp et. al., 2018	States as collaborative; Emphasizes communication skills
	Priven & Sacks, 2016	States as collaborative; Focuses on inter-personal relationships; Develops a project first culture;
	Russel et. al., 2015	States as collaborative; Improved project performance

3.2.1 Critical Path Method (CPM)

CPM has long been the standard method of scheduling and is credited with the initial development of the project management profession (Koskela et. al., 2014). CPM takes a large-scale representation of the project and breaks it down into specific activities with specific and detailed relationships to predecessors and successors. In this way it allows activities to be coordinated and, through the calculation of floats, relays the effects of one activity changing in duration to the activities that immediately follow it through free float, and the project as a whole through total float (Said & Lucko, 2016; Zareei, 2017). This does not however address constraints or outside influences that might affect the project. Additionally, CPM, as the name suggests, is very focused on the critical path and thus pay inadequate attention to non-critical path items that can cause delays and quickly add costs to a project (Hammad et. al., 2018). This same project level review can make it very useful for developing complex high-level plans (El-Sabek et. al., 2018). Also, through specialized software, such as Primavera 6 and Microsoft Project, it can be used to quickly address a lifecycle review of the project (Su & Cai, 2013). This review can help to address project goals as far as meeting scheduled milestones and project deadlines (Said & Lucko, 2016).

So, while CPM at least partially addresses coordination, project goals, and project lifecycle where it falls short in comparison to other scheduling methods in terms of collaboration is in alignment, and engagement. In the literature most of the times CPM is mentioned it refers to a singular entity developing the schedule. Either a planner or a manager and then reviewing it in solidarity or only with management as a top down review tool (Zareei, 2017; Koskela et. al., 2014; Su & Cai, 2013). Additionally, even while praising it for its high level review El-Sabek et. al. caution readers that it is “less functional as a communication tool" (2018). Furthermore, while the calculations and analysis that CPM allows is sited as an advantage of the method there are other references of its inaccuracies (Christodolou, 2018; Hammad et al., 2018). This suggests that while calculations are possible, they are not particularly valuable if the basis of those calculations is not credible. Reasons for doubting the credibility of CPM stem from a failure to incorporate spatial constraints (Su & Cai, 2013) and "the intangible aspects of a project" (Goedert & Sekpe, 2013). The results are that only about half of the weekly activities and tasks scheduled for a project using CPM are completed on time (Koskela et. al., 2014).

With the limited discussion of CPM's benefits and the lengthy documentation of its short comings, particularly when it comes to collaboration leads to an interesting question of why CPM remains the default scheduling method in construction projects? Likely the explanation lies with owner expectations. Over the years CPM has become less a means of scheduling and production control and more a method of contract management (Koskela et. al., 2014) and as such remains a fixture in the AEC industry.

3.2.2 Line of Balance Method (LoB)

Line of Balance is a visual method of displaying the schedule that coordinates location of the work, team doing the work, and the time it is planned to occur. In terms of the collaboration definition it partially implements all five key words of the definition: alignment, engagement, coordination, lifecycle and goals.

The continuity principle is the main objective with the LoB method (Koskela, et. al., 2014). This is its greatest strength and source of its shortcomings. LoB allows all members of the project to quickly visualize the flow of the work and see where they will be and when thus allowing for quick coordination, and the visual nature encourages engagement and allows rapid checking to see if the plan is in alignment with project goals (Deschamps, et. al., 2015; Zhang et. al., 2014). Benefits from this scheduling method include increased planning with sub-contractors to help manage their labor which is even more powerful when learning curves are incorporated with that labor assessment (Zhang et. al., 2014). It also serves as a forecaster for future work based on how well project crews are maintaining the flow specified and avoid waste (Deschamps et. al., 2015).

One significant challenge of utilizing LoB is that it is most readily applied to repetitive projects (Deschamps et. al., 2015; Zhang et. al., 2014). All the literature had it only applied to the project with difficult application outside of those repetitive sections (Sacks et. al., 2019). These limitations are the primary reason that this system is listed as only partially implementing alignment, coordination, goals, and lifecycle of the project. Another reason for partially implemented coordination is that LoB is unable to track material flows (Deschamps et al., 2015). It is only partially implementing engagement since evidence has been found that when using LoB can over prioritize flow to the point where teams can find themselves idle. This is due to the developer of the schedule may review the time increments of the pace, or takt, setting activity but then other activities needed to introduce inefficiencies to adhere to that pace (Deschamps et. al., 2015). It is engaging since it sought the input of the takt setter, but only partially so since it appears that the other trades were not consulted otherwise, they could decouple the faster activities from that takt setter to improve those trades work flow. This may not be a problem for subcontractors in a large area that can balance crews across several projects however a fully engaging method would allow for better management of resources to focus on transformation within a given project.

Where LoB shows tremendous potential is as a schedule visualization method within a larger planning system such as the LPS, Scrum, or CPM so that the many benefits of the method can be employed while still having the other aspects of the scheduling method look at the larger project and coordinate material flows and align project goals to activities throughout all phases of the project.

3.2.3 Scrum or Agile Method

Scrum or Agile scheduling method is most famous for its applications within the software development community. Dingsoyr et. al, show applications of how it can be applied to very large projects that might also include AEC projects (2017). The method is also credited with maximizing value through the intense use of small self-organized teams, flexible technology, and regular customer involvement in an iterative process (Lee & Young, 2013). In relation to the collaboration definition this method fully implements the aspects of engagement and coordination and partially implements alignment, goals, and lifecycle of a project. The partial implementation rating is used not because the literature on the scheduling method does not address alignment, goals, or lifecycle, but rather the it offers a few critiques on the effectiveness of Scrum in alignment, goals, and lifecycle.

Scrum is extremely engaging and focuses on coordination of many activities to achieve a larger goal. Cards that focus on what the activity is, by whom, for whom, by when and how long it will take allow team members to quickly communicate the constraints of an activity and how it aligns to the larger project goals. Additionally, weekly meetings with stakeholders and burn down charts keep project goals and desired end states in mind throughout the lifecycle of the project. (Fruchter, 2011). As projects increase in scale there also needed to be an increased emphasis on “change tolerance, evolutionary delivery, and active end user involvement” to allow the sprints of small projects to coalesce into larger scale projects (Dingsoyr et. al., 2017). The statement regarding end user involvement show how engagement continue to scale with project size while using Scrum and the evolutionary delivery shows the coordination becomes iterative as each new activity tests its interactions with the existing activities of the project. While Dingsoyr et. al., (2017) do not specifically state the applicability of Scrum planning to AEC projects it is easy to draw parallels with their work to the complexity and scale of a construction project and incorporates aspects of lean construction suggesting best practices such as colocation and longer lead planning sessions in addition to the weekly meetings

While the authors referenced above are largely supportive of Scrum or agile planning method, they do offer criticisms that the method only addresses part of the project’s lifecycle (Lee & Young, 2013) and as such alignment with over reaching goals in large projects is also difficult (Dingsoyr, et. al., 2017). This difficulty is only compounded by the fact that Scrum was originally intended for small teams and so aligning several of the small teams to one central effort can prove difficult (Dingsoyer et. al., 2017; Fruchter, 2011).

3.2.4 Last Planner System (LPS)

LPS is a system developed with lean construction methods in mind. It focuses on preserving flow, shielding production, and involving the people that know the most about the process to make commitments regarding its completion. Consequently, it is the only method that was found to fully implement all five aspects of the collaborative scheduling definition. Since it was designed around lean principles it is not surprising that much of the language that is used in the definition of collaborative scheduling from CII RT 362 is also found within the literature for LPS. Where other methods required the author to synthesize given material and subject matter from the text in the case of LPS the aspects of collaborative scheduling were often written verbatim in the works analysed.

Many of the works state outright that an outcome of utilizing LPS raises collaborative behaviour, or that the intent is to foster a collaborative work practice (Ebbs et. al., 2018; Torp et. al., 2018; Priven & Sacks, 2015; Russel et. al., 2015). A more detailed examination of the works confirmed that the referenced authors above definition of collaborative was in agreement with CII RT 362. The method proved to be engaging through its layered planning approach and ensuring buy in, in the form of firm commitments, from the individuals that would own the work (El-Sabek et. al., 2018; Hunt & Gonzalez, 2018) LPS fostered coordination in tasks through the make ready plan and weekly work plan (El-Sabek et. al., 2018; Ebbs et. al, 2018). Others speak of coordination achieved through strengthening communication and personal relationships of the team (Torp et. al., 2018; Priven & Sacks, 2016).

Alignment and goals also feature prominently within the LPS literature. Hunt & Gonzalez (2018) focus on the strength of the client to insist on a performance improvement culture as an alignment feature. El-Sabek et. al. (2018) state how the schedule and specifically the Planned Percent Complete (PPC) is able to function as a steering mechanism to align action to the goals of the project. Priven & Sacks (2016) write on how the improved social subcontract builds team unity and helps develop a culture where project goals supplant individual goals. Then, following alignment of the team, many studies discuss the improved outcomes that can be seen from employment of LPS on a project including decreased schedule, decreased costs, greater value to stakeholders, and even improving the industry as a whole (Ebbs et. al, 2018; Hunt & Gonzalez, 2018; Russel et. al, 2015).

Finally, considerable attention is paid to how LPS evolves over the lifecycle of the project and adapts as activities draw near. The evolution from master schedule to phase planning to look ahead schedule and then to the weekly work plan highlights how the schedule evolves to meet the needs of the project as required. In that lifecycle the activities are reanalysed with the appropriate stakeholders and a double check is made that the commitments are still supportable, and that the activity still adds value to the project. (El-Sabek et. al., 2018; Torp et al, 2018; Russel et. al., 2015). The authors are speaking to the iterative effect of LPS where working from the milestone down to the weekly work plan the team is effectively engaging stakeholders to coordinate activities and ensuring those activities still align to the project goals at each step.

3.3 SOFTWARE REVIEWED

There is a software that has been developed to support each of the scheduling methods above excluding LoB. This is likely due to the fact that LoB is intended to be simple and quick visual method and is likely able to be achieved via basic office software or even just graph paper. Interestingly enough on all of the product web pages the software uses collaboration via real time updates, cloud hosting, or built in notification no matter what scheduling method it supports (Project Management Software- Microsoft Project, 2019; Primavera, 2019; Construction Team Collaboration – TouchPlan, 2019; Monday Team Management Software, 2019; Trello, 2019; What is V Planner, 2019). Additionally, all the software examined offers some kind of mobile device support. Limitations to this section of the paper is that only capabilities of the software were examined, and billing methods were not explored. The purpose is to highlight the breadth of software support available to the different scheduling methods rather than to review or make a cost benefit analysis of each. Table 6 summarizes the findings for the strengths and weaknesses of each software as it enables collaboration.

Table 6: Strenghts and weaknesses of each software as related to collaboration.

Program	Strengths	Drawbacks
Primavera 6	Mobile Support, Real time collaboration, Industry standard, portfolio scalable, oracle support, self-building past performance; advanced reports	Bad for LPS (Ebbs et. al., 2018), Windows only, oracle biased.
MS Project	Mobile Support, Real time collaboration, scalable to portfolio management, large templates, advanced reports	Windows only
Mondays	Mobile Support, Real time collaboration; Portfolio scalable, team management features, built in reporting, system agnostic	No spatial allowance for construction
Trello	Mobile Support, Real time collaboration; System agnostic, simple interface, strong partnerships with other productivity apps	No spatial allowance for construction
VPlanner	Mobile Support, Real time collaboration; LPS based, enables swim lanes, advanced reporting	Windows only

Touch Plan	Mobile Support, Real time collaboration; LPS based, system agnostic,	Limited reporting options
BIM 360	Mobile Support, Real time collaboration; Predictive analytics, portfolio scalable, information consolidation	Windows only, no explicit scheduling function

The industry staples that serve as software support for project management are Primavera 6 by Oracle and Microsoft Project from Microsoft (Project Management Software- Microsoft Project, 2019; Primavera, 2019). These are both modelled to support CPM and offer a heuristic based system for scheduling activities and resource levelling. Each also offers a wide selection of readymade reports and are scalable to serve as program and portfolio managers as well. A drawback is both are dependent upon a windows operating system. For all intents and purposes as far as scheduling method support is concerned the main difference between Microsoft Project and P6 is whether the scheduler prefers Microsoft or Oracle (Project Management Software- Microsoft Project, 2019; Primavera, 2019)

As a method that was developed largely within the software development field it is unsurprising to find two examples that support Scrum planning as well. These two are Trello and Mondays. Both are system agnostic and work via web-based applications. Where they differ is that Trello has a tremendous partnering system to incorporate other business apps such as Dropbox, Google Drive, and Slack. Trello is also exclusively for Scrum support and serves by replicating the cards discussed above online and would be difficult to adapt for construction operations, although might be applicable for the design process. Mondays however has a larger team building and cost modelling function that can be scaled to a program or portfolio level. Mondays also has built in reporting options that could be used to support construction operations via LPS with modification. (Monday Team Management Software, 2019; Trello, 2019).

LPS is the newest of these methods but has two fairly new options for software support in terms of VPlanner and TouchPlan. Both use online collaboration platforms to support the four levels of LPS. Each are capable of automatically scheduling activities based on relationships developed in phase planning. They do however have a few key differences in that first TouchPlan is web based and system agnostic while VPlanner will require a windows operating system. Additionally, V Planner's reporting system is significantly more robust than TouchPlan. Both programs allow for the calculation of Percent Planned Completed but V Planner also has pre-made reports to track commitments, task categories, change history, causes for work not being completed, and allows for CVS exports to incorporate planning efforts into Microsoft Project or Primavera 6.(Construction Team Collaboration – TouchPlan, 2019; What is VPlanner, 2019).

The final software examined was unique in that it did not specifically support any of the scheduling methods. This was Autodesk's BIM 360. It was included due to BIM's 4D modelling capabilities and there was a thought this might translate into scheduling support. This was not the case. However, the program offers support to several other programs and would easily be able to support schedules created in P6 or MS Project, and perhaps in future developments even VPlanner and TouchPlan. Additional capabilities on offer are strong project analytics collected from the schedule and the BIM model to help spot logistical trouble areas over and above Navisworks' collision detection. It is also readily able to scale across multiple BIM models for program and portfolio level management. BIM 360 will however require a Windows based system (Construction Management Software Autodesk BIM 360, 2019).

The inclusion of the software aspect in this paper is not to suggest that software support in and of itself makes a scheduling method more collaborative but mostly to serve as a check against avoiding a specific system because it lacks software support. All of the methods mentioned above have a software that could support them from the specifically tailored systems like Trello, VPlanner, TouchPlan, P6 and MS Project, to the more general programs like Mondays and BIM 360, to generic office software to produce a LoB.

4.0 RESULTS

Based on the definitions derived from the literature review section 3.1 and the textual evidence discussed above in the scheduling methods throughout section 3.2 the Table 7 was tabulated below. The evaluation was a simple rating system that gave zero points if the construct was not implemented, one point if it was partially implemented, and two points if it was fully implemented. Finally, the average score was calculated for final assessment of which scheduling method was the most collaborative.

Table 7: Measure of collaboration for scheduling method through definition keyword examination. From least to most collaborative the methods are CPM, LoB, Scrum and LPS.

Method	Aligns	Engages	Lifecycle	Coordinate	Goals	Avg
Critical Path Method	0 (Koskela et. al., 2014)	0 (Koskela et. al., 2014) (Su & Cai, 2013) (El Sabek & McCabe, 2018)	1 (El Sabek & McCabe, 2018) (Christodolou, 2018)	1 (Zareei, 2017) (Hammad et. al., 2018) (Goedert & Sekpe, 2013)	1 (Said & Lucko, 2016) (Koskela et. al., 2014)	0.6
Line of Balance	1 (Deschamps et. al, 2015) (Zhang et. al., 2014)	1 (Deschamps et. al, 2015) (Zhang et. al., 2014)	1 (Deschamps et. al, 2015) (Zhang et. al., 2014) (Sacks et. al., 2009)	1 (Deschamps et. al, 2015) (Zhang et. al., 2014)	1 (Deschamps et. al, 2015) (Koskela et. al., 2014) (Zhang et. al., 2014)	1.0
Scrum	1 (Dingsoyr et. al., 2017) (Fruchter, 2011)	2 (Dingsoyr et. al., 2017) (Lee & Young, 2013) (Fruchter, 2011)	1 (Dingsoyr et. al., 2017) (Lee & Young, 2013) (Fruchter, 2011)	2 (Dingsoyr et. al., 2017) (Fruchter, 2011)	1 (Dingsoyr et. al., 2017) (Fruchter, 2011)	1.4
Last Planner System	2 (Ebb et. al., 2018) (El-Sabek et. al., 2018) (Hunter & Gonzalez, 2018)	2 (El-Sabek et. al., 2018) (Torp et. al., 2018) (Priven & Sacks, 2016) (Russel et. al., 2015)	2 (El-Sabek et. al., 2018) (Torp et. al., 2018) (Russell, et. al., 2015)	2 (Ebbs et. al., 2018) (El-Sabek et. al., 2018) (Hunt & Gonzalez, 2018) (Torp et. al., 2018)	2 (Ebbs et. al., 2018) (Hunt & Gonzalez, et. al., 2018) (Russel et. al., 2016)	2.0

				(Priven & Sacks, 2016) (Russell, et. al, 2015)		

These results clearly communicate that the scheduling methods, from most collaborative to least collaborative, are LPS, Scrum, LoB, and CPM.

The software that were studied were rated in a similar scale where zero is does not support the scheduling method, one is partial supports the scheduling method or could be supported with some modifications, and two is fully supports the scheduling method. The results are tabulated in Table 8.

Table 8: Software support for scheduling method.

Program	CPM	Last Planner	Scrum	Line of Balance
P6	2	0	0	0
MS Project	2	0	0	0
V Planner	0	2	0	0
Trello	0	0	2	0
BIM 360	1	1	0	1
Mondays	0	1	2	0
Touch Plan	0	2	0	0

The main takeaway from what Table 8 provides is that regardless of what scheduling method chosen there is a software tool readily available to support that method. Unfortunately, what is lacking is schedule tool that readily implements multiple scheduling methods to provide various views for production management. Consequently, the project team will need to assess the project goals, team make up and chose what software best software offers the easiest engagement platform to ensure team alignment and coordination across the lifecycle of the project.

5.0 CONCLUSIONS

The definition of collaborative scheduling put forward by CII RT 362, "A comprehensive process that aligns and engages stakeholders throughout the lifecycle of the project in order to coordinate activities and resources on a project and achieve its goal" has, through an extensive literature review of over seven hundred sources pulled from a targeted BOOLEAN search, shown to be valid and in line with current research. Additionally, there is a significant relationship between the aspects of team alignment and project goals as well as between team engagement and activity coordination.

Through a similarly expansive literature review referencing the above definition it has been shown qualitatively that the scheduling methods examined within this paper, CPM, LoB, Scrum, and LPS, can be evaluated by CII RT 362 definition. And when so evaluated there is ample textual evidence to state that from most to least collaborative the scheduling methods are LPS, Scrum, LoB, and CPM.

The software in support of construction operations is mature enough to support any of the above methods. Although no one program is able to support any method there are multiple options to support any given scheduling method a project team wished to employ.

Future research could feature statistical review of collaborative scheduling methods performance in terms of project goals and team satisfaction to those of less collaborative methods. Additionally, further investigation into software support and whether it produces better project results as opposed to analogue methods is worthy of additional study.

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